UNITED STATES PATENT APPLICATION FOR

DUAL INPUT AND OUTLET ELECTROSTATIC AIR TRANSPORTER-CONDITIONER

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Claim of Priority:

[0001] This application claims priority from provisional application entitled "DUAL INPUT AND OUTLET ELECTROSTATIC AIR TRANSPORTER-CONDITIONER," Application No. 60/340,288, filed December 13, 2001 under 35 U.S.C. 119(e), which application is incorporated herein by reference. This application claims priority from provisional application entitled "FOCUS ELECTRODE, ELECTRO-KINETIC AIR TRANSPORTER-CONDITIONER DEVICES," Application No. 60/306,479, filed July 18, 2001 under 35 U.S.C. 119(e), which application is incorporated herein by reference. This application claims priority from and is a continuation-in-part of U.S. Patent Application No. 09/924,624 filed August 8, 2001 which is a continuation of U.S. Patent No. 09/564,960 filed May 4, 2000, which is a continuation-in-part of U.S. Patent Application No. 09/186,471 filed November 5, 1998, now U.S. Patent No. 6,176,977, all of which are incorporated herein by reference.

Cross-Reference to Related Applications:

[0002] 1. U.S. Patent Application No. 60/341,518, filed December 13, 2001, entitled "ELECTRO-KINETIC AIR TRANSPORTER-CONDITIONER DEVICES WITH AN UPSTREAM FOCUS ELECTRODE"; SHPR-01041US6

[0003] 2. U.S. Patent Application No. 60/341,090, filed December 13, 2001, entitled "ELECTRO-KINETIC AIR TRANSPORTER-CONDITIONER DEVICES WITH TRAILING ELECTRODE"; SHPR-01041USE

[0004] 3. U.S. Patent Application No. 60/341,433, filed December 13, 2001, entitled "ELECTRO-KINETIC AIR TRANSPORTER-CONDITIONER DEVICES WITH INTERSTITIAL ELECTRODE"; SHPR-01041USF

[0005] 4. U.S. Patent Application No. 60/341, 592, filed December 13, 2001, entitled "ELECTRO-KINETIC AIR TRANSPORTER-CONDITIONER DEVICES WITH ENHANCED COLLECTOR ELECTRODE"; SHPR-01041USG

[0006] 5. U.S. Patent Application No. 60/341,320, filed December 13, 2001, entitled "ELECTRO-KINETIC AIR TRANSPORTER-CONDITIONER DEVICES WITH ENHANCED EMITTER ELECTRODE"; SHPR-01041USH

[0007] 6. U.S. Patent Application No. 60/341,179, filed December 13, 2001, entitled "ELECTRO-KINETIC AIR TRANSPORTER AND CONDITIONER DEVICE WITH ENHANCED ANTI-MICROORGANISM CAPABILITY"; SHPR-01028US1

[0008] 7. U.S. Patent Application No. 60/340,702, filed December 13, 2001, entitled "ELECTRO-KINETIC AIR TRANSPORTER AND CONDITIONER DEVICE WITH ENHANCED HOUSING CONFIGURATION AND ENHANCED ANTI-MICROORGANISM CAPABILITY"; SHPR-01028US2

[0009] 8. U.S. Patent Application No. 60/341,377, filed December 13, 2001, entitled "ELECTRO-KINETIC AIR TRANSPORTER AND CONDITIONER DEVICE WITH ENHANCED MAINTENANCE FEATURES AND ENHANCED ANTI-MICROORGANISM CAPABILITY"; SHPR-01028US3

[0010] 9. U.S. Patent Application No. 10/023,197, filed December 13, 2001, entitled "ELECTRO-KINETIC AIR TRANSPORTER-CONDITIONER DEVICE WITH ENHANCED CLEANING FEATURES"; SHPR-01041USI

[0011] 10. U.S. Patent Application No. 10/023,460, filed December 13, 2001, entitled "ELECTRO-KINETIC AIR TRANSPORTER CONDITIONER WITH PIN-RING ELECTRODE CONFIGURATION"; SHPR-01041USJ

[0012] 11. U.S. Patent Application No. 60/341,176, filed December 13, 2001, entitled "ELECTRO-KINETIC AIR TRANSPORTER-CONDITIONER WITH NON-EQUIDISTANT COLLECTOR ELECTRODES"; SHPR-01041US8

[0013] 12. U.S. Patent Application No. 60/340,462, filed December 13, 2001, entitled "ELECTRO-KINETIC AIR TRANSPORTER-CONDITIONER DEVICES WITH A ENHANCED COLLECTOR ELECTRODE FOR COLLECTION OF MORE PARTICULATE MATTER"; SHPR-01041US9

[0014] 13. U.S. Patent Application No. 10/xxx,xxx, filed herewith, entitled "ELECTRO-KINETIC AIR TRANSPORTER-CONDITIONER DEVICES WITH AN UPSTREAM FOCUS ELECTRODE"; SHPR-01041USL

[0015] 14. U.S. Patent Application No. 10/xxx,xxx, filed herewith, entitled "ELECTRO-KINETIC AIR TRANSPORTER-CONDITIONER DEVICES WITH TRAILING ELECTRODE"; SHPR-01041USM

[0016] 15. U.S. Patent Application No. 10/xxx,xxx, filed herewith, entitled "ELECTRO-KINETIC AIR TRANSPORTER-CONDITIONER DEVICES WITH INTERSTITIAL ELECTRODE"; SHPR-01041USN

[0017] 16. U.S. Patent Application No. 10/xxx,xxx, filed herewith, entitled "ELECTRO-KINETIC AIR TRANSPORTER-CONDITIONER DEVICES WITH ENHANCED COLLECTOR ELECTRODE"; SHPR-01041USO

[0018] 17. U.S. Patent Application No. 10/xxx,xxx, filed herewith, entitled "ELECTRO-KINETIC AIR TRANSPORTER-CONDITIONER DEVICES WITH ENHANCED EMITTER ELECTRODE"; SHPR-01041USP

[0019] 18. U.S. Patent Application No. 10/xxx,xxx, filed herewith, entitled "ELECTRO-

KINETIC AIR TRANSPORTER AND CONDITIONER DEVICE WITH ENHANCED ANTI-MICROORGANISM CAPABILITY"; SHPR-01028US4

[0020] 19. U.S. Patent Application No. 10/xxx,xxx, filed herewith, entitled "ELECTRO-KINETIC AIR TRANSPORTER AND CONDITIONER DEVICE WITH ENHANCED HOUSING CONFIGURATION AND ENHANCED ANTI-MICROORGANISM CAPABILITY"; SHPR-01028US5

[0021] 20. U.S. Patent Application No. 10/xxx,xxx, filed herewith, entitled "ELECTRO-KINETIC AIR TRANSPORTER AND CONDITIONER DEVICE WITH ENHANCED MAINTENANCE FEATURES AND ENHANCED ANTI-MICROORGANISM CAPABILITY"; SHPR-01028US6

[0022] 21. U.S. Patent Application No. 10/xxx,xxx, filed herewith, entitled "ELECTRO-KINETIC AIR TRANSPORTER-CONDITIONER WITH NON-EQUIDISTANT COLLECTOR ELECTRODES"; SHPR-01041USQ and

[0023] 22. U.S. Patent Application No. 10/xxx,xxx, filed herewith, entitled "ELECTRO-KINETIC AIR TRANSPORTER-CONDITIONER DEVICES WITH A ENHANCED COLLECTOR ELECTRODE FOR COLLECTION OF MORE PARTICULATE MATTER". SHPR-01041USS.

[0024] All of the above are incorporated herein by reference.

Field of the Invention:

[0025] This invention relates generally to devices that produce an electro-kinetic flow of air, from which particulate matter has been substantially removed.

Background of the Invention:

[0026] The use of an electric motor to rotate a fan blade to create an airflow has long been known in the art. Unfortunately, such fans produce substantial noise, and can present a hazard to

children who may be tempted to poke a finger or a pencil into the moving fan blade. Although such fans can produce substantial airflow, e.g., 1,000 ft^3/minute or more, substantial electrical power is required to operate the motor, and essentially no conditioning of the flowing air occurs.

[0027] It is known to provide such fans with a HEPA-compliant filter element to remove particulate matter larger than perhaps 0.3 μm. Unfortunately, the resistance to airflow presented by the filter element may require doubling the electric motor size to maintain a desired level of airflow. Further, HEPA-compliant filter elements are expensive, and can represent a substantial portion of the sale price of a HEPA-compliant filter-fan unit. While such filter-fan units can condition the air by removing large particles, particulate matter small enough to pass through the filter element is not removed, including bacteria, for example.

[0028] It is also known in the art to produce an airflow using electro-kinetic techniques, by which electrical power is directly converted into a flow of air without mechanically moving components. One such system is described in U.S. Patent No. 4,789,801 issued to Lee (1988), which is incorporated herein by reference. The '801 patent describes various devices to generate a stream of ionized air using so-called electro-kinetic techniques. In some applications, the electro-kinetic devices may be small enough to be handheld, and in other applications electro-kinetic devices may be large enough to condition the air in a room. In overview, electro-kinetic techniques use high electric fields to ionize air molecules, a process that may produce ozone (O_3) as a byproduct. Ozone is an unstable molecule of oxygen that is commonly produced as a byproduct of high voltage arcing. In appropriate concentrations, ozone can be a desirable and useful substance. But ozone by itself may not be effective to kill microorganisms such as germs, bacteria, and viruses in the environment surrounding the device.

[0029] Fig. 1 depicts a generic electro-kinetic device **10** to condition air. Device **10** includes a housing **20** that typically has at least one air input port **30** and at least one air output port **40**. Within housing **20** there is disposed an electrode assembly or system **50** comprising a first electrode array **60** having at least one electrode **70** and comprising a second electrode array **80**

having at least one electrode **90**. System **10** further includes a high voltage generator **95** coupled between the first and second electrode arrays.

[0030] As a result, ozone and ionized particles of air are generated within device **10**, and there is an electro-kinetic flow of air in the direction from the first electrode array **60** towards the second electrode array **80**. In Fig. 1, the large arrow denoted IN represents ambient air that can enter input port **30**. The small "x's" denote particulate matter that may be present in the incoming ambient air. The air movement is in the direction of the large arrows, and the output airflow, denoted OUT, exits device **10** via port **40**. An advantage of electro-kinetic devices such as device **10** is that an airflow is created without using fans or other moving parts to create the airflow.

[0031] Preferably, particulate matter in the ambient air can be electrostatically attracted to the second electrode array **80**, with the result that the outflow (OUT) of air from device **10** not only contains ozone and ionized air, but can be cleaner than the ambient air. Thus, device **10** in Fig. 1 can function somewhat as a fan to create an output airflow, but without requiring moving parts. Ideally the outflow of air (OUT) is conditioned in that particulate matter is removed and the outflow includes appropriate amounts of ozone, and some ions.

[0032] As shown in Fig. 2A, system **50** includes an array of first ("emitter") electrodes or conductive surfaces **70** that are spaced-apart symmetrically from an array of second ("collector") electrodes or conductive surfaces **90**. The positive terminal of a generator such as, for example, pulse generator **95** that outputs a train of high voltage pulses (e.g., 0 to perhaps + 5 KV) is coupled to the first array, and the negative pulse generator terminal is coupled to the second array in this example. It is to be understood that the arrays depicted include multiple electrodes, but that an array can include or be replaced by a single electrode.

[0033] The high voltage pulses ionize the air between the arrays, and create an airflow from the first array toward the second array, without requiring any moving parts. Particulate matter **60** in the air is entrained within the airflow and also moves towards the second electrodes **90**. Much of the particulate matter **60** is electrostatically attracted to the surfaces of the second electrodes **90**,

where it remains, thus conditioning the flow of air exiting system **50**. Further, the high voltage field present between the electrode arrays can release ozone into the ambient environment, which can eliminate odors that are entrained in the airflow.

[0034] In the particular embodiment of Fig. 2A, first electrodes **70** are circular in cross-section, having a diameter of about 0.003" (0.08 mm), whereas the second electrodes **90** are substantially larger in area and define a "teardrop" shape in cross-section. The ratio of cross-sectional radii of curvature between the bulbous front nose of the second electrode and the first electrodes exceeds 10:1. As shown in Fig. 2A, the bulbous front surfaces of the second electrodes **90** face the first electrodes **70**, and the somewhat "sharp" trailing edges face the exit direction of the airflow. The "sharp" trailing edges on the second electrodes **90** promote good electrostatic attachment of particulate matter entrained in the airflow.

[0035] In another particular embodiment shown herein as Fig. 2B, second electrodes **90** are symmetrical and elongated in cross-section. The elongated trailing edges on the second electrodes **90** provide increased area upon which particulate matter entrained in the airflow can attach.

[0036] While the electrostatic techniques disclosed by the '801 patent are advantageous over conventional electric fan-filter units, further increased air transport-conditioning efficiency would be advantageous.

Summary of the Invention:

[0037] An aspect of an embodiment of the present invention is to provide an electro-kinetic system for transporting and conditioning air without moving parts. An embodiment includes an ion generator comprising first and second conducting electrodes or surfaces. The first and second electrodes are coupled to output ports of a high voltage generator.

[0038] Another aspect of an embodiment of the present invention is to remove dust and other particulate matter from the airflow. The dust and particulate matter attaches electrostatically to the second electrodes, and the output air is substantially clean of such particulate matter.

[0039] Yet another aspect of the present invention is to produce ozone to reduce or kill certain types of germs and the like. Ozone is also beneficial for eliminating odors in the output air. An embodiment of the invention permits the user to temporarily increase the high voltage pulse generator output which creates more ozone, e.g., to more rapidly eliminate odors in the environment.

[0040] Still another aspect of an embodiment of the present invention is to increase the airflow rate of the device while not increasing the amount of ozone output into the atmosphere. An embodiment includes a second array of electrodes, or collector electrodes, where several of the second electrodes are recessed back, further away from the first array of electrodes. This configuration can reduce the amount of high-voltage arcing within the ion generator, which can produce ozone.

[0041] Other features and advantages of the invention will appear from the following description in which the preferred embodiments have been set forth in detail, in conjunction with the accompanying drawings, and also from the following claims.

<u>Brief Description of the Drawings:</u>

[0042] FIG. 1 is a schematic of prior-art electro-kinetic device with an electrode assembly;

[0043] FIGS. 2A-2B; Fig. 2A is a plan view of a first and second electrode arrays of a prior art electrode assembly; Fig. 2B is a plan view of another embodiment of first and second electrode arrays according to a prior art electrode assembly;

[0044] FIGS. 3A-3B; Fig. 3A is a perspective view of an embodiment of the housing of the present invention; Fig. 3B is a perspective view of the housing shown in Fig. 3A, illustrating a removable array of second electrodes;

[0045] FIG. 4 is an electrical block diagram of an embodiment of the ion generator assembly, according to the present invention;

[0046] FIGS. 5A-5D; Fig. 5A is a perspective view illustrating an embodiment for an

electrode assembly of the present invention; Fig. 5B is a plan view of the electrode assembly shown in Fig. 5A; Fig. 5C is a perspective view of another embodiment of an electrode assembly of the present invention; Fig. 5D is a plan view of yet another embodiment of an electrode assembly of the present invention;

[0047] FIGS. 6A-6F; Fig. 6A is a perspective view of an embodiment of the electrode assembly, according to the present invention; Fig. 6B is a plan view of the embodiment illustrated in Fig. 6A; Fig. 6C is a perspective view of another embodiment of the electrode assembly, according to the present invention; Fig. 6D is a plan view of another embodiment of the present invention; Fig. 6E is a perspective view of still another embodiment of the electrode assembly, according to the present invention; Fig. 6F is a plan view of an alternative embodiment of the invention;

[0048] FIGS. 7A-7B; Fig. 7A is a perspective view of yet another embodiment of the electrode assembly, according to the present invention; Fig. 7B is a plan view of the embodiment shown in Fig. 7A;

[0049] FIGS. 8A-8C; Fig. 8A is a plan view of another embodiment of the electrode assembly, according to the present invention; Fig. 8B is a plan view of yet another embodiment of the present invention; Fig. 8C is a plan view of a modified embodiment of that shown in Fig. 8B;

[0050] FIGS. 9A-9B; Fig. 9A is a perspective view of still another embodiment of the electrode assembly; Fig. 9B is a perspective view of a modified embodiment of that shown in Fig. 9A;

[0051] FIGS. 10A-10F; Fig. 10A is a plan view of another embodiment of the electrode assembly of the present invention; Fig. 10B is a plan view of a modified embodiment of that shown in Fig. 10A; Fig. 10C is a plan view of yet another embodiment of the electrode assembly, according to the present invention; Fig. 10D is a plan view of a modified embodiment of that shown in Fig. 10C; Fig. 10D is a plan view of yet another embodiment of the electrode assembly of the present invention; Fig. 10F is a plan view of a modified embodiment of the electrode assembly as

shown in Fig. 10E;

[0052] FIGS. 11A-11C; Fig. 11A is a perspective view of yet another embodiment of the electrode assembly of the present invention; Fig. 11B is a perspective view of another embodiment of the electrode assembly of the present invention ; Fig. 11C is a perspective view of still another embodiment of the electrode assembly of the present invention;

<u>Detailed Description of the Preferred Embodiment</u>

<u>Overall Air Transporter-Conditioner Device Configuration</u>:

[0053] Figs. 3A and 3B depict an electro-kinetic air transporter-conditioner system **100** whose housing **102** includes preferably rear-located intake vents or louvers **104** and preferably front located exhaust vents **106**, and a base pedestal **108**. Preferably the housing is freestanding and/or upstandingly vertical and/or elongated. Internal to the transporter housing is an ion generating unit **160**, preferably powered by an AC:DC power supply that is energizable or excitable using switch **S1**. **S1**, which along with the other below described user operated switches are conveniently located at the top **103** of the unit **100**. Ion generating unit **160** is self-contained in that other ambient air, nothing is required from beyond the transporter housing, save external operating potential, for operation of the present invention.

[0054] The upper surface of housing **102** includes a user-liftable handle member **112** to which is affixed a second array **240** of collector electrodes **242** within an electrode assembly **220**. Electrode assembly **220** also comprises a first array of emitter electrodes **230**, or a single first electrode shown here as a single wire or wire-shaped electrode **232**. (The terms "wire" and "wire-shaped" shall be used interchangeably herein to mean an electrode either made from a wire or, if thicker or stiffer than a wire, having the appearance of a wire.) In the embodiment shown, lifting member **112** lifts second array electrodes **240** upward, causing the second electrode to telescope out of the top of the housing and, if desired, out of unit **100** for cleaning, while the first electrode array **230** remains within unit **100**. As is evident from the figure, the second array of electrode can

be lifted vertically out from the top **103** of unit **100** along the longitudinal axis or direction of the elongated housing **102**. This arrangement with the second electrodes removable from the top **103** of the unit **100**, makes it easy for the user to pull the second electrodes out for cleaning. In Fig. 2B, the bottom ends of second electrodes **242** are connected to a member **113**, to which is attached a mechanism **500**, which includes a flexible member and a slot for capturing and cleaning the first electrode **232**, whenever handle member **112** is moved upward or downward by a user.

[0055] The general shape of the embodiment of the invention shown in Figs. 3A and 3B is that of a figure eight in cross-section, although other shapes are within the spirit and scope of the invention. The top-to-bottom height of the preferred embodiment is in one preferred embodiment, 1 m, with a left-to-right width of preferably 15 cm, and a front-to-back depth of perhaps 10 cm, although other dimensions and shapes can of course be used. A louvered construction provides ample inlet and outlet venting in an economical housing configuration. There need be no real distinction between vents **104** and **106**, except their location relative to the second electrodes. These vents serve to ensure that an adequate flow of ambient air can be drawn into or made available to the unit **100**, and that an adequate flow of ionized air that includes appropriate amounts of O_3 flows out from unit **100**.

[0056] The first and second arrays of electrodes are coupled to the output terminals of ion generating unit **160**, as best seen in Fig. 4. As will be described, when unit **100** is energized with **S1**, high voltage or high potential output by ion generator **160** produces ions at the first electrode, which ions are attracted to the second electrodes. The movement of the ions in an "IN" to "OUT" direction carries with the ions air molecules, thus electro-kinetically producing an outflow of ionized air. The "IN" notation in Figs. 3A and 3B denote the intake of ambient air with particulate matter **60**. The "OUT" notation in the figures denotes the outflow of cleaned air substantially devoid of the particulate matter, which particulates matter adheres electrostatically to the surface of the second electrodes. In the process of generating the ionized airflow appropriate amounts of ozone (O_3) are beneficially produced. It may be desired to provide the inner surface of housing **102** with an

electrostatic shield to reduces detectable electromagnetic radiation. For example, a metal shield could be disposed within the housing, or portions of the interior of the housing can be coated with a metallic paint to reduce such radiation.

[0057] As best seen in Fig. 4, ion generating unit **160** includes a high voltage generator unit **170** and circuitry **180** for converting raw alternating voltage (e.g., 117 VAC) into direct current ("DC") voltage. Circuitry **180** preferably includes circuitry controlling the shape and/or duty cycle of the generator unit output voltage (which control is altered with user switch **S2**). Circuitry **180** preferably also includes a pulse mode component, coupled to switch **S3**, to temporarily provide a burst of increased output ozone. Circuitry **180** can also include a timer circuit and a visual indicator such as a light emitting diode ("LED"). The LED or other indicator (including, if desired, an audible indicator) signals when ion generation quits occurring. The timer can automatically halt generation of ions and/or ozone after some predetermined time, e.g., 30 minutes.

[0058] The high voltage generator unit **170** preferably comprises a low voltage oscillator circuit **190** of perhaps 20 KHz frequency, that outputs low voltage pulses to an electronic switch **200**, e.g., a thyristor or the like. Switch **200** switchably couples the low voltage pulses to the input winding of a step-up transformer **T1**. The secondary winding of **T1** is coupled to a high voltage multiplier circuit **210** that outputs high voltage pulses. Preferably the circuitry and components comprising high voltage pulse generator **170** and circuit **180** are fabricated on a printed circuit board that is mounted within housing **102**. If desired, external audio input (e.g., from a stereo tuner) could be suitably coupled to oscillator **190** to acoustically modulate the kinetic airflow produced by unit **160**. The result would be an electrostatic loudspeaker, whose output airflow is audible to the human ear in accordance with the audio input signal. Further, the output air stream would still include ions and ozone.

[0059] Output pulses from high voltage generator **170** preferably are at least 10 KV peak-to-peak with an effective DC offset of, for example, half the peak-to-peak voltage, and have a frequency of, for example, 20 KHz. Frequency of oscillation can include other values, but

frequency of at least about 20KHz is preferred as being inaudible to humans. If pets will be in the same room as the unit **100**, it may be desired to utilize and even higher operating frequency, to prevent pet discomfort and/or howling by the pet. The pulse train output preferably has a duty cycle of for example 10%, which will promote battery lifetime if live current is not used. Of course, different peak-peak amplitudes, DC offsets, pulse train waveshapes, duty cycle, and/or repetition frequencies can be used instead. Indeed, a 100% pulse train (e.g., an essentially DC high voltage) may be used, albeit with shorter battery lifetime. Thus, generator unit **170** for this embodiment can be referred to as a high voltage pulse generator. Unit **170** functions as a DC:DC high voltage generator, and could be implemented using other circuitry and/or techniques to output high voltage pulses that are input to electrode assembly **220**.

[0060] As noted, outflow (OUT) preferably includes appropriate amounts of ozone that can remove odors and preferably destroy or at least substantially alter bacteria, germs, and other living (or quasi-living) matter subjected to the outflow. Thus, when switch **S1** is closed and the generator **170** has sufficient operating potential, pulses from high voltage pulse generator unit **170** create an outflow (OUT) of ionized air and ozone. When **S1** is closed, LED will visually signal when ionization is occurring.

[0061] Preferably operating parameters of unit **100** are set during manufacture and are generally not user-adjustable. For example, with respect to operating parameters, increasing the peak-to-peak output voltage and/or duty cycle in the high voltage pulses generated by unit **170** can increase the airflow rate, ion content, and ozone content. These parameters can be set by the user by adjusting switch **S2** as disclosed below. In the preferred embodiment, output flowrate is about 200 feet/minute, ion content is about 2,000,000/cc and ozone content is about 40 ppb (over ambient) to perhaps 2,000 ppb (over ambient). Decreasing the ratio of the radius of the nose of the second electrodes to the radius of the first electrode or decreasing the ratio of the cross-sectioned area of the second electrode to the first electrode below about 20:1 will decrease flow rate, as will decreasing the peak-to-peak voltage and/or duty cycle of the high voltage pulses

coupled between the first and second electrode arrays.

[0062] In practice, unit **100** is placed in a room and connected to an appropriate source of operating potential, typically **117** VAC. With **S1** energizing ionization unit **160**, systems **100** emits ionized air and preferably some ozone via outlet vents **106**. The airflow, coupled with the ions and ozone freshens the air in the room, and the ozone can beneficially destroy or at least diminish the undesired effects of certain odors, bacteria, germs, and the like. The airflow is indeed electro-kinetically produced, in that there are no intentionally moving parts within unit **100**. (Some mechanical vibration may occur within the electrodes.).

[0063] Having described various aspects of this embodiment of the invention in general, preferred embodiments of electrode assembly **220** are now described. In the various embodiments, electrode assembly **220** comprises a first array **230** of at least one electrode or conductive surface **232**, and further comprises a second array **240** of at least one electrode or conductive surface **242**. Understandably materials for electrodes **232** and **242** should conduct electricity, be resistant to corrosive effects from the application of high voltage, yet be strong enough to be cleaned.

[0064] In the various electrode assemblies to be described herein, electrodes **232** in the first electrode array **230** are preferably fabricated from tungsten. Tungsten is sufficiently robust in order to withstand cleaning, has a high melting point to retard breakdown due to ionization, and has a rough exterior surface that seems to promote efficient ionization. On the other hand, electrodes **242** preferably have a highly polished exterior surface to minimize unwanted point-to-point radiation. As such, electrodes **242** preferably are fabricated from stainless steel and/or brass, among other materials. The polished surface of electrodes **232** also promotes ease of electrode cleaning.

[0065] In contrast to the prior art electrodes disclosed by the '801 patent, electrodes **232** and **242**, are light weight, easy to fabricate, and lend themselves to mass production. Further, electrodes **232** and **242** described herein promote more efficient generation of ionized air, and appropriate amounts of ozone, (indicated in several of the figures as O_3).

Electrode Assembly with First and Second Electrodes:

Figs. 5A-5D

[0066] Figs. 5A-5B illustrate various configurations of the electrode assembly **220**. The electrode assembly **220** comprises a first array **230** of wire electrodes **232-1**, **232-2**, and **232-3** (collectively referred to as "electrodes **232**"), and a second array **240** of generally "U"-shaped electrodes **242-1**, **242-2**, **242-3**, and **242-4** (collectively referred to as "electrodes **242**"). In preferred embodiments, the number N1 of electrodes comprising the first array **230** will preferably differ by one relative to the number N2 of electrodes comprising the second array **240**. In many of the embodiments shown, N2>N1. However, additional first electrodes **232** could be added (e.g., electrodes **232-4**, **232-5**, etc.) such that N1>N2.

[0067] Electrodes **232** are preferably lengths of tungsten wire, whereas the hollow elongated "U"-shaped electrodes **242** are formed from sheet metal, preferably stainless steel, although brass or other sheet metal could be used. The sheet metal is formed to define side regions **244** and a rounded nose region **246**. While particulate matter (not shown) is present in the incoming (IN) air, the outflow (OUT) air is substantially devoid of particulate matter, which adheres to the preferably large surface area provided by the second electrodes **242**. The output air may, or may not, contain ozone.

[0068] As best seen in Fig. 5B, the spaced-apart configuration between the arrays is preferably staggered such that each first array electrode **232** is substantially equidistant from each second array electrode **242**. This symmetrical staggering has been found to be an especially efficient electrode placement. Preferably the staggering geometry is symmetrical in that adjacent electrodes **232** or adjacent electrodes **242** are spaced-apart a constant distance, Y1 and Y2 respectively with the electrodes **232** preferably centered between each electrode **242**. However, a non-symmetrical configuration is within the spirit and scope of this invention.

[0069] In Figs. 5A-5B, typical dimensions are as follows: diameter of electrodes **232** is about 0.08 mm, distances Y1 and Y2 are each about 16 mm, distance X1 is about 16 mm,

distance L is about 20 mm, and electrode heights Z1 and Z2 are each about 1 m. The width W of electrodes **242** is preferably about 4 mm, and the thickness of the material from which electrodes **242** are formed is about 0.5 mm. Of course, other dimensions and shapes could be used. It is preferred that electrodes **232** be small in diameter to help establish a desired high voltage field. On the other hand, it is desired that electrodes **232**, as well as electrodes **242**, be sufficiently robust to withstand occasional cleaning.

[0070] Fig. 5B illustrates theoretical electric field lines that ions will travel along from a first electrode **232** to a second electrode **242.** In this configuration, ions strike the second electrode **242-2** along two paths, as shown by directional flow paths B and C. Similarly, ions strike the second electrode **242-3** along two flow paths, as shown by directional flow paths D and E. The second electrodes **242-1** and **242-4** attract ions primarily only along a single path, as shown by directional flow paths A and F, respectively.

[0071] As shown in Fig. 5B, the directional flow of ions emitted from the first electrode **232** contact the nose area **246** of the second electrode **242**. A higher amount of energy is generated at the nose **246** than the trailing sides **244** of each second electrode **242**. Thus, the second electrodes **242-2, 242-3** generate upwards of about twice as much energy as the second electrodes **242-1, 242-4** since they receive ions from two flow paths instead of one. Accordingly, each second electrode will not have a similar electric field at the nose **246**. In this embodiment, the second electrodes **242-2, 242-3** will have a similar strength, and be higher than the second electrodes **242-1, 242-4**. Thus, the array of second electrodes **240** will have an unbalanced electrical field at each nose **246**. As a result, the second electrodes **242-2, 242-3** may generate a higher amount of ozone than the second electrodes **242-1, 242-4**.

[0072] Each electrode **232** in the first array **230** is coupled by a conductor **234** to a first (preferably positive) output port of high voltage pulse generator **170**, and each electrode **242** in the second array **240** is coupled by a conductor **249** to a second (preferably negative) output port of generator **170**. It is relatively unimportant where on the various electrodes electrical connection

is made to conductors **234** or **249**. By way of example only, Fig. 5B depicts conductor **249** making connection with some electrodes **242** internal to the nose end **246**, while other electrodes **242** make electrical connection to conductor **249** elsewhere on the electrode. An electrical connection to the various electrodes **242** could also be made on the electrode external surface providing no substantial impairment of the outflow airstream results; however, it has been formed to be preferable that the connection is made internally.

[0073] In this and the other embodiments to be described hereinafter, ionization appears to occur at the electrode **232** in the first electrode array **230**, with ozone production occurring as a function of high voltage arcing. For example, increasing the peak-to-peak voltage amplitude and/or duty cycle of the pulses from the high voltage pulse generator **170** can increase ozone content in the output flow of ionized air. If desired, user-control S2 can be used to somewhat vary ozone content by varying (in an appropriate manner) amplitude and/or duty cycle. Specific circuitry for achieving such control is known in the art and need not be described in detail herein.

[0074] Note the inclusion in Figs. 5A-5B of at least one output controlling electrode **243**, preferably electrically coupled to the same potential as the second array electrodes **242**. Electrode **243** preferably defines a pointed shape in side profile, e.g., a triangle. The sharp point on electrodes **243** causes the generation of substantial negative ions (since the electrode is coupled to relatively negative high potential). These negative ions neutralize excess positive ions otherwise present in the output airflow, such that the "OUT" flow has a net negative charge. Electrodes **243** preferably are stainless steel, copper, or other conductor, and are perhaps 20 mm high and about 12 mm wide at the base.

[0075] In Fig. 5C and the figures to follow, the particulate matter is omitted for ease of illustration. However, from what was shown in Figs. 5A-5B, particulate matter will be present in the incoming air, and will be substantially absent from the outgoing air. As has been described, particulate matter **60** typically will be electrostatically precipitated upon the surface area of electrodes **242**.

[0076] As discussed above and as depicted by Fig. 5C, it is relatively unimportant where on an electrode array electrical connection is made. Thus, first array electrodes **232** are shown electrically connected together at their bottom regions by conductor **234**, whereas second array electrodes **242** are shown electrically connected together in their middle regions by the conductor **249**. Both arrays may be connected together in more than one region, e.g., at the top and at the bottom. It is preferred that the wire or strips or other inter-connecting mechanisms be at the top, bottom, or periphery of the second array electrodes **242**, so as to minimize obstructing stream air movement through the housing **210**.

[0077] It is noted that the embodiments of Figs. 5C and 5D depict somewhat truncated versions of the second electrodes **242**. Whereas dimension L in the embodiment of Figs. 5A and 5B was about 20 mm, in Figs. 5C and 5D, L has been shortened to about 8 mm. Other dimensions in Fig. 5C preferably are similar to those stated for Figs. 5A and 5B. It will be appreciated that the configuration of second electrode array **240** in Fig. 5C can be more robust than the configuration of Figs. 5A and 5B, by virtue of the shorter trailing edge geometry. As noted earlier, a symmetrical staggered geometry for the first and second electrode arrays is preferred for the configuration of Fig. 5C.

[0078] In the embodiment of Fig. 5D, the outermost second electrodes, denoted **242-1** and **242-4**, have substantially no outermost trailing edges. Dimension L in Fig. 5D is preferably about 3 mm, and other dimensions may be as stated for the configuration of Figs. 5A and 5B. Again, the ratio of the radius or surface areas between the first electrode **232** and the second electrodes **242** for the embodiment of Fig. 5D preferably exceeds about 20:1.

<u>Electrode Assembly with Recessed/Non-Equidistant Second Electrodes:</u>

[0079] Having described various aspects of the invention in general, preferred embodiments of electrode assembly **220** will now be described.

FIGS. 6A-6F

[0080] Figs. 6A-6B illustrate an electrode assembly **220** including a first array **230** of wire-shaped electrodes **232-1**, **232-2**, and **232-3** (collectively referred to as "electrodes **232**"), and a second array **240** of generally "U"-shaped electrodes **242-1**, **242-2**, **242-3**, and **242-4** (collectively referred to as "electrodes **242**"). In this configuration, the second electrodes **242-2**, **242-3** are located further "downstream" than second electrodes **242-1**, **242-4**. Thus the electrodes positioned in the middle of the array are removed further downstream than the electrode and the outer edges of the array. Preferably, the second electrodes **242-2, 242-3** are located the same distance away from the first array **230**, as shown by the distance X2. For example, the second electrodes **242-1**, **242-4** are located a distance X1 downstream from the first electrodes **232**, while the second electrodes **242-2**, **242-3** are located a distance X2 downstream from the first electrodes **232**. By way of example only, X2 is preferably 4mm to 6 mm longer than X1. The distance X2 can also be 2mm to 12mm larger than X1. The distance X2 is preferably greater than X1 so that the strength of the electric field generated at the nose **246** of each second electrode **242** is substantially similar. Accordingly, this configuration will produce lower amounts of ozone than the embodiment shown in Figs. 5A-5B. It is within the spirit and scope of the invention for X2 to be longer or shorter.

[0081] Fig. 6B illustrates theoretical ion directional flow paths **A**, **B**, **C**, **D**, **E**, and **F**. Each ion flow path A-F generally represents the path ions travel from a first electrode **232** to a second electrode **242**. As previously mentioned, each second electrode **242** generates an electric field primarily at the nose **246**, and is proportional to the quantity of ions that contact the electrode and the distance the ions travel before reaching the second electrode **242**. Ions are emitted from the first electrodes **232**. Ions lose the electrical charge as a function of time. Accordingly, an ion that travels a short distance, for example X1, will generate a stronger electrical field when it contacts the nose **246** than an ion that travels a distance X2 before contacting the nose **246**.

[0082] The second electrode **242-2** primarily receives ions along flow paths **B**, **C**, while the

second electrode **242-3** primarily receives ions along flow paths **D**, **E**. Normally, if all four second electrodes **242** were located the distance X1 downstream from the first electrodes **232**, as shown in Figs. 5A-5B, a stronger electrical field will occur at the nose **246** of second electrodes **242-2**, **242-3** because these two second electrodes collect substantially more ions as electrodes **242-1**, **242-4**.

[0083] The distance X2 is preferably greater than X1 so that the strength of the electric field generated at the nose **246** of each second electrode **242** is substantially similar. The second electrodes **242-2**, **242-3** still receive more ions than the second electrodes **242-1**, **242-4**. However, the additional distance each ion must travel, shown by X2-X1, will substantially offset the additional number of ions received. Accordingly, this configuration will produce lower amounts of ozone than the embodiment shown in Figs. 5A-5B

[0084] Fig. 6C illustrates a preferred configuration of the embodiment shown in Fig. 5C. The second electrodes **242-2** and **242-3** are recessed downstream a distance X2 from the first array **230**, which the second electrodes **242-1** and **242-4** remain a distance X1 downstream of the first array of electrodes **230**. Similar to the embodiment shown in Figs. 5A-5B, the second electrode **242-2** and **242-3** receive substantially more ions than the second electrodes **242-1** or **242-2**. However, the strength of the electric field generated at the nose **246** of each second electrode **242** is preferably similar because of the additional distance each ion must travel to reach the recessed electrodes **242-2** and **242-3**.

[0085] Fig. 6D illustrates a preferred configuration of the embodiment shown in Fig. 5D. Again, the second electrodes **242-2** and **242-3** are recessed downstream a distance X2 from the first array **230**, which the second electrodes **242-1** and **242-4** remain a distance X1 downstream of the first array of electrodes **230**. Similar to the embodiment shown in Figs. 5A-5B, the second electrode **242-2** and **242-3** receive substantially more ions than the second electrodes **242-1** or **242-2**. However, the strength of the electric field generated at the nose **246** of each second electrode **242** is preferably similar because of the additional distance each ion must travel to reach

the recessed electrodes **242-2** and **242-3**.

[0086] Figs. 6E-6F illustrate that the second electrodes **242** may have angled or corrugated extensions **294**. Preferably, the tail **294** is a non-linear configuration, having an effective width W′ greater than the width W (see Fig. 5B) of the second electrode **242**. In Fig. 6E the trailing downstream portion is provided at an angle to the leading, upstream or nose portion. Thus, the extension **294** provides a wider structure than the nose **246** of the second electrode **242**. The extensions **294** enhance the particle capture efficiency of the electrode assembly **220**.

[0087] In general, larger airborne particles (e.g., one micron and larger) tend to have their own significant forward momentum in the air stream. A "U"-shaped second electrode **242** without an angled blade extension **294**, as shown in Fig. 5A, might allow a larger particle to pass through the electrode assembly **220** uncaptured. The momentum of the particle may prevent it from contacting the trailing edges of the second electrode **242**. The increased width W' of the angled extension **246** is intended to capture the larger particles. For example, if the larger particle passes by the trailing side **244** of the second electrode **242** uncaptured, but the particle is within W' of the trailing sides **244**, the particle will be captured by the extension **294**. It is within the spirit and scope of the invention for the extension **246** to comprise other non-linear shapes and configurations such as, but not limited to, a "U"-shape, an "L"-shape, a Z-shape, a shape with a first upstream portion and a second down stream portion provided at an angle to the upstream portion, and a shape with a tail section that is wider in the stream of airflow than the upstream, leading or nose portion. Tail sections **294** can be directed in the same direction and be parallel as depicted, or the tail sections can be configured to diverge from each other in order to form a "V" or a "Y" configuration adjacent to the outlet vent. Thus the upper tail sections **294** as shown in Fig. 6E are made to point upwardly on the page, with the lower two tail sections **294** remaining pointing downwardly on the page.

Electrode Assembly with Recessed/Non-Equidistant Second Electrodes and an Upstream Focus Electrode:

FIGS. 7A-7B

[0088] The embodiments illustrated in Figs. 7A-7B are somewhat similar to the previously described embodiments in Figs. 6A-6B. The electrode assembly **220** includes a first array of electrodes **230** and a second array of electrodes **240**. Again, for this and the other embodiments, the term "array of electrodes" may refer to a single electrode or a plurality of electrodes. Preferably, the number of electrodes **232** in the first array of electrodes **230** will differ by one relative to the number of electrodes **242** in the second array of electrodes **240**. The distances L, X1, Y1, Y2, Z1 and Z2 for this embodiment are similar to those previously described in Fig. 5A.

[0089] As shown in Fig. 7A, the electrode assembly **220** preferably adds a third, or leading, or focus, or directional electrode **224a**, **224b**, **224c** (generally referred to as "electrode **224**") upstream of each first electrode **232-1, 232-2, 232-3**. The focus electrode **224** produces an enhanced airflow velocity exiting the devices **100**. In general, the third focus electrode **224** directs the airflow, and ions generated by the first electrode **232,** towards the second electrodes **242**. Each third focus electrode **224** is a distance X3 upstream from at least one of the first electrodes **232**. The distance X3 is preferably 5-6 mm, or four to five diameters of the focus electrode **224**. However, the third focus electrode **224** can be further from or closer to the first electrode **232**.

[0090] The third focus electrode **224** illustrated in Fig. 7A is a rod-shaped electrode. The

third focus electrode **224** can also comprise other shapes that preferably do not contain any sharp edges. The third focus electrode **224** is preferably manufactured from material that will not erode or oxidize, such as stainless steel. The diameter of the third focus electrode **224**, in a preferred embodiment, is at least fifteen times greater than the diameter of the first electrode **232**. The diameter of the third focus electrode **224** can be larger or smaller. The diameter of the third focus electrode **224** is preferably large enough so that third focus electrode **224** does not function as an ion emitting surface when electrically connected with the first electrode **232**. The maximum diameter of the third focus electrode **224** is somewhat constrained. As the diameter increases, the third focus electrode **224** will begin to noticeably impair the airflow rate of the unit **100**. Therefore, the diameter of the third electrode **224** is balanced between the need to form a non-ion emitting surface and airflow properties of the unit **100**.

[0091] In a preferred embodiment, each third focus electrodes **224a**, **224b**, **224c** are electrically connected with the first array **230** and the high voltage generator **170** by the conductor **234**. As shown in Fig. 7A, the third focus electrodes **224** are electrically connected to the same positive outlet of the high voltage generator **170** as the first array **230**. Accordingly, the first electrode **232** and the third focus electrode **224** generate a positive electrical field. Since the electrical fields generated by the third focus electrode **224** and the first electrode **232** are both positive, the positive field generated by the third focus electrode **224** can push, or repel, or direct, the positive field generated by the first electrode **232** towards the second array **240**. For example, the positive field generated by the third focus electrode **224a** will push, or repel, or direct, the

positive field generated by the first electrode **232-1** towards the second array **240**. In general, the third focus electrode **224** shapes the electrical field generated by each electrode **232** in the first array **230**. This shaping effect is believed to decrease the amount of ozone generated by the electrode assembly **220** and increases the airflow of the unit **100**.

[0092] The particles within the airflow are positively charged by the ions generated by the first electrode **232**. As previously mentioned, the positively charged particles are collected by the negatively charged second electrodes **242**. The third focus electrode **224** also directs the airflow towards the second electrodes **242** by guiding the charged particles towards the trailing edges **244** of each second electrode **242**. It is believed that the airflow will travel around the third focus electrode **224**, partially focusing the airflow towards the trailing edges **244**, improving the collection rate of the electrode assembly **220**.

[0093] The third focus electrode **224** may be located at various positions upstream of each first electrode **232**. By way of example only, a third focus electrode **224b** is located directly upstream of the first electrode **232-2** so that the center of the third focus electrode **224b** is in-line and symmetrically aligned with the first electrode **232-2**, as shown by extension line B. Extension line B is located midway between the second electrode **242-2** and the second electrode **242-3**. Alternatively, a third focus electrode **224** can also be located at an angle relative to the first electrode **232**. For example, a third focus electrode **224a** can be located upstream of the first electrode **232-1** along a line extending from the middle of the nose **246** of the second electrode **242-2** through the center of the first electrode **232-1**, as shown by extension line A. The third focus

electrode **224a** is in-line and symmetrically aligned with the first electrode **232-1** along extension line A. Similarly, the third electrode **224c** is located upstream to the first electrode **232-3** along a line extending from the middle of the nose **246** of the second electrode **242-3** through the first electrode **232-3**, as shown by extension line C. The third focus electrode **224c** is in-line and symmetrically aligned with the first electrode **232-3** along extension line C. It is within the scope of the present invention for the electrode assembly **220** to include third focus electrodes **224** that are both directly upstream and at an angle to the first electrodes **232**, as depicted in Fig. 7A.

[0094] Again, as with the prior embodiments, the innermost second electrodes **242-2** and **242-3** are recessed back from the first array of electrodes **230**, and receive the advantages previously disclosed.

<u>FIGS. 8A-8D</u>

[0095] Fig. 8A-8B illustrates an electrode assembly **220** including a first array of electrodes **230** having three wire-shaped first electrodes **232-1**, **232-2**, **232-3** (generally referred to as "electrode **232**") and a second array of electrodes **240** having four "U"-shaped second electrodes **242-1**, **242-2**, **242-3**, **242-4** (generally referred to as "electrode **242**"). Each electrode **232** is electrically connected to the high voltage generator **170** at the bottom region, whereas the second electrodes **242** are electrically connected to the high-voltage generator **170** in the middle to illustrate that the first and second electrodes **232**, **242** can be electrically connected in a variety of locations.

[0096] The second electrode **242** in Fig. 8A is a similar version of the second electrode **242** shown in Fig. 5C. The distance L has been shortened to about 8mm, while the other dimensions X1, Y1, Y2, Z1, Z2 are similar to those shown in Fig. 5A.

[0097] A third leading or focus electrode **224** is located upstream of each first electrode **232**. The innermost third focus electrode **224b** is located directly upstream of the first electrode **232-2**, as shown by extension line B. Extension line B is located midway between the second electrodes **242-2, 242-3**. The third focus electrodes **224a, 224c** are at an angle with respect to the first electrodes **232-1, 232-3**. For example, the third focus electrode **224a** is upstream to the first electrode **232-1** along a line extending from the middle of the nose **246** of the second electrode **242-2** extending through the center of the first electrode **232-1**, as shown by extension line A. The third electrode **224c** is located upstream of the first electrode **232-3** along a line extending from the center of the nose **246** of the second electrode **242-3** through the center of the first electrode **232-3**, as shown by extension line C. Accordingly and preferably the focus electrodes fan out relative to the first electrodes as an aid for directing the flow of ions and charged particles.

[0098] Fig. 8B illustrates third focus electrodes **224** added to the electrode assembly **220** shown in Fig. 5D. Preferably, a third focus electrode **224** is located upstream of each first electrode **232**. For example, the third focus electrode **224b** is in-line and symmetrically aligned with the first electrode **232-2**, as shown by extension line B. Extension line B is located midway between the second electrodes **242-2, 242-3**. The third focus electrode **224a** is in-line and symmetrically aligned with the first electrode **232-1**, as shown by extension line A. Similarly, the

third electrode **224c** is in-line and symmetrically aligned with the first electrode **232-3**, as shown by extension line C. Extension lines A-C extend from the middle of the nose **246** of the "U"-shaped second electrodes **242-2**, **242-3** through the first electrodes **232-1**, **232-3**, respectively. In a preferred embodiment, the third electrodes **224a**, **224b**, **224c** with the high voltage generator **170** by the conductor **234**. This embodiment can also include a pair of third focus electrodes **224** upstream of each first electrode **232**.

[0099] Fig. 8C illustrates pairs of third focus electrodes **224** added to the electrode assembly **220** shown in Fig. 5D. Preferably, a pair of third focus electrodes **224** are located upstream of each first electrode **232**. For example, the pair of third focus electrodes **224b** and **224b'** are in-line and symmetrically aligned with the first electrode **232-2**, as shown by extension line B. Extension line B is located midway between the second electrodes **242-2**, **242-3**. The pair of third focus electrodes **224a** and **224a'** are in-line and symmetrically aligned with the first electrode **232-1**, as shown by extension line A. Similarly, the pair of third electrodes **224c** and **224c'** are in-line and symmetrically aligned with the first electrode **232-3**, as shown by extension line C. Extension lines A-C extend from the middle of the nose **246** of the "U"-shaped second electrodes **242-2**, **242-3** through the first electrodes **232-1**, **232-3**, respectively. In a preferred embodiment, only the third electrodes **224a**, **224b**, **224c** are electrically connected to the high voltage generator **170** by the conductor **234**, and the third electrodes **224a'**, **224b'**, and **224c'** have a floating potential.

[0100] In the embodiment of Figs. 8A-8C, the middle second electrodes are recessed a

distance X2 downstream for the reasons stated in the previous embodiments. Again, as with the prior embodiments, the innermost second electrodes **242-2** and **242-3** are recessed back from the first array of electrodes **230**, and receive the advantages previously disclosed.

FIGS. 9A-9B

[0101] The previously described embodiments of the electrode assembly **220** disclose a rod- shaped third focus electrode **224** upstream of each first electrode **232**. Fig. 9A illustrates an alternative configuration for the third focus electrode **224**. By way of example only, the electrode assembly **220** may include a "U"-shaped or possibly "L"-shaped third focus electrode **224** upstream of each first electrode **232**. Further the third focus electrode **224** can have other curved configurations such as, but not limited to, circular-shaped, elliptical-shaped, and other concave shapes facing the first electrode **232**. In a preferred embodiment, the third focus electrode **224** has holes **225** extending through, forming a perforated surface to minimize the resistance of the third focus electrode **224** on the airflow rate.

[0102] In a preferred embodiment, the third focus electrode **224** is electrically connected to the high voltage generator **170** by conductor **234**. The third focus electrode **224** in Figs. 9A-9B is preferably not an ion emitting surface. Similar to previous embodiments, the third focus electrode **224** generates a positive electric field and pushes or repels the electric field generated by the first electrode **232** towards the second array **240**.

[0103] Fig. 9A illustrates that a perforated "U"-shaped third focus electrode **224** can be

incorporated into the electrode assembly **220** shown in Fig. 5A. Even though only two configurations of the electrode assembly **220** are shown with the perforated "U"-shaped, or parabolic shaped, third focus electrode **224**, all the embodiments described in Figs. 6A-13 may incorporate the perforated "U"-shaped, or parabolic shaped, third focus electrode **224**. It is also within the scope of the invention to have multiple perforated "U"-shaped, or parabolic shaped, third focus electrodes **224** upstream of each first electrode **232**. Further, in other embodiments, the "U"-shaped third focus electrode can be made of a screen or mesh.

[0104] Fig. 9B illustrates third focus electrodes **224** similar to those depicted in Fig. 9A, except that the third focus electrodes **224** are rotated by 180° to preset a convex surface facing to the first electrodes **232** in order to focus and direct the field of ions and airflow from the first electrode **232** toward the second electrode **242**. These third focus electrodes **224** shown in Figs. 9A-9B are located along extension lines A, B, C similar to previously described embodiments.

[0105] Again, as with the prior embodiments, the innermost second electrodes **242-2** and **242-3** are recessed back from the first array of electrodes **230**, and receive the advantages previously disclosed.

<u>Electrode Assemblies With Various Combinations of Focus Electrode, Trailing Electrodes and Second Electrodes With Protective Ends:</u>

<u>Figs. 10A-10D</u>

[0106] Fig. 10A illustrates an electrode assembly **220** that includes a first array of

electrodes **230** having two wire-shaped electrodes **232-1**, **232-2** (generally referred to as "electrode **232**") and a second array of electrodes **240** having three "U"-shaped electrodes **242-1**, **242-2**, **242-3** (generally referred to as "electrode **242**"). This configuration is in contrast to, for example, the configurations of Fig. 8A, wherein there are three first emitter electrodes **232** and four second collector electrodes **242**. Upstream from each first electrode **232**, at a distance X2, is a third focus electrode **224**. Each third focus electrode **224a**, **224b** is at an angle with respect to a first electrode **232**. For example, the third focus electrode **224a** is preferably along a line extending from the middle of the nose **246** of the second electrode **242-2** through the center of the first electrode **232-1**, as shown by extension line A. The third focus electrode **224a** is in-line and symmetrically aligned with the first electrode **232-1** along extension line A. Similarly, the third focus electrode **224b** is located along a line extending from middle of the nose **246** of the second electrode **242-2** through the center of the first electrode **232-2**, as shown by extension line B. The third focus electrode **224b** is in-line and symmetrically aligned with the first electrode **232-2** along extension line B. As previously described, the diameter of each third focus electrode **224** is preferably at least fifteen times greater than the diameter of the first electrode **232**. As shown in Fig. 10A, and similar to the embodiment shown in Fig. 5B, each second electrode preferably has a protective end **241**. In a preferred embodiment, the third focus electrodes **224** are electrically connected to the high voltage generator **170** (not shown). It is within the spirit and scope of the invention to not electrically connect the third focus electrodes **224**.

[0107] Fig. 10B illustrates that multiple third focus electrodes **224** may be located upstream

of each first emitter electrode **232**. For example, the third focus electrode **224a2** is in-line and symmetrically aligned with the third focus electrode **224a1** along extension line A. Similarly, the third focus electrode **224b2** is in-line and symmetrically aligned with the third focus electrode **242b1** along extension line B. It is within the scope of the present invention to electrically connect all, or none of, the third focus electrodes **224** to the high-voltage generator **170**. In a preferred embodiment, only the third focus electrodes **224a1**, **224b1** are electrically connected to the high voltage generator **170**, with the third focus electrodes **224a2**, **224b2** having a floating potential.

[0108] Fig. 10C illustrates that the electrode assembly **220** shown in Fig. 10A may also include a trailing electrode **245** downstream of each second electrode **242**. Each trailing electrode **245** is in-line with the second electrode so as not to interfere with airflow past the second electrode **242**. Each trailing electrode **245** is preferably located a distance downstream of each second electrode **242** equal to at least three times the width W of the second electrode **242**. Other distances are within the scope of the invention. It is within the scope of the present invention for the trailing electrode to by located at other distances downstream. The diameter of the trailing anode **245** is preferably no greater than the width W of the second electrode **242** to limit the interference of the airflow coming off the second electrode **242**.

[0109] One aspect of the trailing electrode **245** is to direct the air trailing off the second electrode **242** and provide a more laminar flow of air exiting the outlet **260**. Another aspect of the trailing electrode **245** is to neutralize the positive ions generated by the first array **230** and collect particles within the airflow. As shown in Fig. 10C, each trailing electrode **245** is electrically

connected to a second electrode **242** by a conductor **248**. Thus, the trailing electrode **245** is negatively charged, and serves as a collecting surface, similar to the second electrode **242**, attracts the positively charged particles in the airflow. As previously described, the electrically connected trailing electrode **245** also emits negative ions to neutralize the positive ions emitted by the first electrodes **232**.

[0110] Fig. 10D illustrates that a pair of third focus electrodes **224** may be located upstream of each first electrode **232**. For example, the third focus electrode **224a2** is upstream of the third focus electrode **224a1** so that the third focus electrodes **224a1**, **224a2** are in-line and symmetrically aligned with each other along extension line A. Similarly, the third focus electrode **224b2** is in line and symmetrically aligned with the third focus electrode **224b1** along extension line B. As previously described, preferably only the third focus electrodes **224a1**, **224b1** are electrically connected to the high voltage generator **170**, while the third focus electrodes **224a2**, **224b2** have a floating potential. It is within the spirit and scope of the present invention to electrically connect all, or none, of the third focus electrodes to the high voltage generator **170**.

[0111] Again, as with the prior embodiments, the innermost second electrode **242-2** is recessed back from the first array of electrodes **230**, and receives the advantages previously disclosed.

<u>Electrode Assemblies With Second Collector Electrodes Having Interstitial Electrodes:</u>

[0112] Fig. 10E illustrates another embodiment of the electrode assembly **220** with an

interstitial electrode **246**. In this embodiment, the interstitial electrode **246** is located midway between the second electrodes **242**. For example, the interstitial electrode **246a** is located midway between the second electrodes **242-1**, **242-2**, while the interstitial electrode **246b** is located midway between second electrodes **242-2**, **242-3**. Preferably, the interstitial electrode **246a**, **246b** are electrically connected to the first electrodes **232**, and generate an electrical field with the same positive or negative charge as the first electrodes **232**. The interstitial electrode **246** and the first electrode **232** then have the same polarity. Accordingly, particles traveling toward the interstitial electrode **246** will be repelled by the interstitial electrode **246** towards the trailing sides **244** of the second electrodes **242**. Alternatively, the interstitial electrodes can have a floating potential or be grounded.

[0113] It is to be understood that interstitial electrodes **246a**, **246b** may also be closer to one second collector electrode than to the other. Also, the interstitial electrodes **246a**, **246b** are preferably located substantially near or at the protective end **241** or ends of the trailing sides **244**, as depicted in Fig. 10E. Still further the interstitial electrode can be substantially located along a line between the two trailing portions or ends of the second electrodes. These rear positions are preferred as the interstitial electrodes can cause the positively charged particle to deflect towards the trailing sides **244** along the entire length of the negatively charged second collector electrode **242**, in order for the second collector electrode **242** to collect more particles from the airflow.

[0114] Still further, the interstitial electrodes **246a**, **246b** can be located upstream along the trailing side **244** of the second collector electrodes **244**. However, the closer the interstitial

electrodes **246a, 246b** get to the nose **246** of the second electrode **242**, generally the less effective interstitial electrodes **246a, 246b** are in urging positively charged particles toward the entire length the second electrodes **242**. Preferably, the interstitial electrodes **246a, 246b** are wire-shaped and smaller or substantially smaller in diameter than the width "W" of the second collector electrodes **242**. For example, the interstitial electrodes can have a diameter of, the same as, or on the order, of the diameter of the first electrodes. For example, the interstitial electrodes can have a diameter of one-sixteenth of an inch. Also, the diameter of the interstitial electrodes **246a, 246b** is substantially less than the distance between second collector electrodes, as indicated by Y2. Further the interstitial electrode can have a length or diameter in the downstream direction that is substantially less than the length of the second electrode in the downstream direction. The reason for this size of the interstitial electrodes **246a, 246b** is so that the interstitial electrodes **246a, 246b** have a minimal effect on the airflow rate exiting the device **200**.

[0115] Fig. 10F illustrates that the electrode assembly **220** in Fig. 10E can include a pair of third electrodes **224** upstream of each first electrode **232**. As previously described, the pair of third electrodes **224** are preferably in-line and symmetrically aligned with each other. For example, the third electrode **224a2** is in-line and symmetrically aligned with the third electrode **224a1** along extension line A. Extension line A preferably extends from the middle of the nose **246** of the second electrode **242-2** through the center of the first electrode **232-1**. As previously disclosed, in a preferred embodiment, only the third electrodes **224a1, 224b1** are electrically connected to the high voltage generator **170**. In Fig. 10F, a plurality of interstitial electrodes **246a** and **246b** are

located between the second electrodes **242**. Preferably these interstitial electrodes are in-line and have a potential gradient with an increasing voltage potential on each successive interstitial electrode in the downstream direction in order to urge particles toward the second electrode. In this situation the voltage on the interstitial electrodes would have the same sign as the voltage on the first electrodes **232**.

[0116] Again, as with the prior embodiments, the innermost second electrode **242-2** is recessed back from the first array of electrodes **230**, and receive the advantages previously disclosed.

Electrode Assembly With an Enhanced First Emitter Electrodes:

FIGS. 11A-11C

[0117] The previously described embodiments of the electrode assembly **220** include a first array of electrodes **230** having at least one wire-shaped electrode **232**. It is within the scope of the present invention for the first array of electrodes **230** to contain electrodes consisting of other shapes and configurations.

[0118] Fig. 11A illustrates that the first array of electrodes **230** may include curved wire-shaped electrodes **252**. The curved wire-shaped electrode **252** is an ion emitting surface and generates an electric field similar to the previously described wire-shaped electrodes **232**. Also similar to previous embodiments, each second electrode **242** is "downstream," and each third focus electrode **224** is "upstream," to the curved wire-shaped electrodes **252**. The electrical properties

and characteristics of the second electrode **242** and the third focus electrode **224** are similar to the previously described embodiment shown in Fig. 6A. It is to be understood that an alternative embodiment of Fig. 11A can exclude the focus electrodes and be within the spirit and scope of the invention.

[0119] As shown in Fig. 11A, positive ions are generated and emitted by the first electrode **252**. In general, the quantity of negative ions generated and emitted by the first electrode is proportional to the surface area of the first electrode. The height Z1 of the first electrode **252** is equal to the height Z1 of the previously disclosed wire-shaped electrode **232**. However, the total length of the electrode **252** is greater than the total length of the electrode **232**. By way of example only, and in a preferred embodiment, if the electrode **252** was straightened out the curved or slack wire electrode **252** is 15-30% longer than a rod or wire-shaped electrode **232**. The electrode **252** is allowed to be slack to achieve the shorter height Z1. When a wire is held slack, the wire may form a curved shape similar to the first electrode **252** shown in Fig. 11A. The greater total length of the electrode **252** translates to a larger surface area than the wire-shaped electrode **232**. Thus, the electrode **252** will generate and emit more ions than the electrode **232**. Ions emitted by the first electrode array attach to the particulate matter within the airflow. The charged particulate matter is attracted to, and collected by, the oppositely charged second collector electrodes **242**. Since the electrodes **252** generate and emit more ions than the previously described electrodes **232**, more particulate matter will be removed from the airflow.

[0120] Fig. 11B illustrates that the first array of electrodes **230** may include flat coil wire-

shaped electrodes **254**. Each flat coil wire-shaped electrode **254** also has a larger surface area than the previously disclosed wire-shaped electrode **232**. By way of example only, if the electrode **254** was straightened out, the electrode **254** will have a total length that is preferably 10% longer than the electrode **232**. Since the height of the electrode **254** remains at Z1, the electrode **254** has a "kinked" configuration as shown in Fig. 11B. This greater length translates to a larger surface area of the electrode **254** than the surface area of the electrode **232**. Accordingly, the electrode **254** will generate and emit a greater number of ions than electrode **232**. It is to be understood that an alternative embodiment of Fig. 11B can exclude the focus electrodes and be within the spirit and scope of the invention.

[0121] Fig. 11C illustrates that the first array of electrodes **230** may also include coiled wire-shaped electrodes **256**. Again, the height Z1 of the electrodes **256** is similar to the height Z1 of the previously described electrodes **232**. However, the total length of the electrodes **256** is greater than the total length of the electrodes **232**. In a preferred embodiment, if the coiled electrode **256** was straightened out the electrodes **256** will have a total length two to three times longer than the wire-shaped electrodes **232**. Thus, the electrodes **256** have a larger surface area than the electrodes **232**, and generate and emit more ions than the first electrodes **232**.The diameter of the wire that is coiled to produce the electrode **256** is similar to the diameter of the electrode **232**. The diameter of the electrode **256** itself is preferably 1-3mm, but can be smaller in accordance with the diameter of first emitter electrode **232**. The diameter of the electrode **256** shall remain small enough so that the electrode **256** has a high emissivity and is an ion emitting

surface. It is to be understood that an alternative embodiment of Fig. 11C can exclude the focus electrodes and be within the spirit and scope of the invention.

[0122] The electrodes **252**, **254** and **256** shown in Figs. 11A-11C may be incorporated into any of the electrode assembly **220** configurations previously disclosed in this application.

[0123] Again, as with the prior embodiments, the innermost second electrodes **242-2** and **242-3** are recessed back from the first array of electrodes **230**, and receive the advantages previously disclosed.

[0124] The foregoing description of the preferred embodiments of the present invention has been provided for the purposes of illustration and description. It is not intended to be exhaustive or to limit the invention to the precise forms disclosed. Obviously, many modifications and variations will be apparent to the practitioner skilled in the art. Embodiments were chosen and described in order to best describe the principles of the invention and its practical application, thereby enabling others skilled in the art to understand the invention, the various embodiments and with various modifications that are suited to the particular use contemplated. It is intended that the scope of the invention be defined by the following claims and their equivalents.

[0125] Modifications and variations may be made to the disclosed embodiments without departing from the subject and spirit of the invention as defined by the following claims.